京都大学	博士（　工　学　）	氏名	方　　堃
論文題目	Progression and onset of undercut slope failure observed by surface velocity in physical models subjected to arch action （アーチ作用を受けた法尻掘削破壊進行とその誘因に関する表面速度に着目した物理模型実験）		

（論文内容の要旨）

According to the concern with the slope in Mae Moh mine during excavation and arching effect in undercut slopes, the major objectives of this research are to study the method of shear pins and inverse velocity in order to stabilize and predict failure time in undercut slope and to investigate the failure mechanisms of undercut slope involving arch effect subjected to groundwater seepage and excavation with different shapes by 1g and centrifugal physical modelling.

Chapter 1: Introduction
The background is introduced. The objectives and range of the research are given with the structure of the thesis. The definitions of arching effect including active arch action and passive arch action are explained. In addition, unstable slopes in Mae Moh mine are briefly introduced as well as engineering challenges.

Chapter 2: Literature review
The current state of knowledge with regard to soil arching, slope stabilization method, failure time prediction in slopes and base failure are reviewed. Besides, PIV and centrifuge modelling as useful experimental techniques are also reported.

Chapter 3: Basic Laboratory tests
Silica sand No.6 and Edosaki sand are selected and checked thru basic laboratory tests in order to prepare physical model tests in 1g and centrifuge condition. In preliminary tests, Edosaki sand with 10 % water content can prevent water leakage in high centrifugal acceleration.

Chapter 4: Physical modelling of undercut slope with reinforcement by pencil leads
Stabilizing pencil leads with diameter 2 mm used to simulate shear pins in different arrangements were investigated by physical models. The pencil leads with good conductivity representing as shear pins can be achieved by means of a current loop system to examine the integrality in the physical model tests. With the monitoring apparatus, double arch action was found in the three vertical rows of 5 shear pins, which increases the stability of undercut slope. The pencil leads can be achieved by means of a current loop system to examine the integrality of shear pins in the physical model tests.

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Chapter 5: Physical modelling of undercut slope with failure prediction using inverse velocity approach

An accurate method using image analysis is applied for measuring surface velocity in undercut slope near the onset of failure in 1g and centrifugal condition. Analyzing algorithm and principle of velocity measurement are discussed together with suitable criteria of setting on the examination area and time frame interval in the undercut slope. Slope failure time prediction technique following Fukuzono's approach (1985) was examined and compared. Eulerian description in image analysis for velocity measurement has a good agreement with Lagrangian description for slope failure prediction.

Chapter 6: Physical models on base failure of slope subjected to surcharge loading

The base failure of slope subjected to surcharge loading was investigated through a series of 1g physical model tests. According to slippage tests with and without side supports, the assumption of lateral stress at the top plane and at the bottom plane (Rankine's passive earth pressure) is proposed and checked. By adding surcharges, the slopes were collapsed either by bilinear slab failure or ploughing failure. The failure modes were dominated by the base angle rather than the slope angle.

Chapter 7: Centrifugal modelling of undercut slope with groundwater seepage

The stability of undercut slopes under the groundwater seepage was studied by geotechnical centrifuge modelling with different water supply rates and pre-excavation widths. The failure modes including arch failure, partial arch failure and whole failure were founded and affected by the undercut span and water supply rate. The passive arching effect also works with the occurrence of seepage flow in a short time.

Chapter 8: Physical modelling of undercut slope with different shapes

A series of physical model tests of undercut slope with different shapes were conducted. With the assist of a high-speed camera and a PIV camera, progressive arch failures were found in the unparallel case (Base 12 cm and top 6 cm) with a shorter excavation width. Both larger failure area and quicker failure velocity in unparellel (Base 6 cm and Top 12 cm) represent more serious consequence with more energy.

Chapter 9: Conclusions and future work

The results in undercut slopes are summarized and future work is also mentioned.

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（論文審査の結果の要旨）

本研究の目的は，法尻斜面掘削の安定性のメカニズムを解明し，実験的研究成果を踏まえて，露天掘り鉱山の法尻掘削における斜面崩壊の予測など，定性的アプローチに関する議論について深めている．得られた主な成果は次のとおりである．

１．抑止杭の配置の違いが斜面崩壊にもたらす影響について，抑止杭の配置の違いに着目し，法尻掘削における斜面の物理模型実験により検討を加えて，また，斜面勾配に関する検討も行った．さらに，遠心模型実験を用いて，浸透を考慮した法尻掘削による影響についても考察を加えた．

２．物理模型実験により，高速度カメラを用い，法尻掘削による斜面の表面移動速度を測定し，速度逆数値の経時変化について分析することで，斜面の表面に現れる挙動の把握を試みた．その結果，速度逆数値によって，斜面に崩壊面が発生する時刻の予測が可能であることを明らかにした．

本論文は，鉱山が対象とされる現場に限らず，世界各地での掘削中の斜面安定の課題に取り組み，抑止杭の配置や斜面勾配および浸透の影響について実験したものである．斜面の表面移動量などの貴重な実験データが得られたことは，非常に意義が高いものであると言え、学術上，実際上寄与するところが少なくない．よって，本論文は博士（工学）の学位論文として価値があるものと認める．また，平成３１年２月２２日，論文内容とそれに関連した事項について試問を行い，申請者が博士後期課程学位取得基準を満たしていることを確認し，合格と認めた．

なお，本論文は，京都大学学位規程第１４条第２項に該当するものと判断し，公表に際しては，（平成 32 年 12 月 31 日までの間）当該論文の全文に代えてその内容を要約したものとすることを認める．